



## 1998 BMDO Technologies—

### Improving the Environment



BALLISTIC MISSILE DEFENSE ORGANIZATION

**1998 BMDO Technologies—  
Improving the Environment**



**Ballistic Missile Defense Organization**

## Foreword

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A sensor technology originally developed to track missiles becomes a device to measure the level of pollutants in automobile exhaust. New versions of capacitors originally developed to provide pulsed power for space-based lasers are being used in products for purifying water. These are examples of technology transfer.

Since the early 1980s, the United States has encouraged industry to partner with Federal agencies to transfer and commercialize Federally funded research and development. Tapping into the Federal resources, businesses grow, taxpayer dollars are maximized, and the Nation gets an edge in what is now a highly competitive global market. Legislation has provided the incentives so that Federal R&D programs and laboratories can actively participate in technology transfer activities, such as licensing agreements, joint partnerships, and cooperative research.

This report has been written in support of the Ballistic Missile Defense Organization's (BMDO's) Technology Applications program. It is intended to put users of environmental technology in touch with developers of innovations funded by BMDO. BMDO has funded a wide range of Defense technologies that could also assist these users in their needs for complying with environmental regulations, obtaining decision-related data, and meeting their bottom lines. Interested readers can obtain contact information on researchers at the mentioned businesses, universities, and Federal laboratories at the end of each story.

The Technology Applications program welcomes any questions and comments about this report, or requests for the other reports. Readers can contact us at the following address:

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Cover photo of tree courtesy of Linda Voss.



## Introduction

### ***The Ballistic Missile Defense Organization: Advanced Technology for a Strong Defense***

The end of the Cold War relaxed tensions between the United States and the former Soviet Union and reduced concerns about nuclear war involving intercontinental ballistic missiles; however, a major new threat emerged: the spread of ballistic missile technology and weapons of mass destruction in new parts of the world. Currently as many as nine nations possess nuclear weapons and several others either can develop nuclear weapons or have active programs. In addition, more than 30 developing nations have chemical weapons programs and over a dozen have biological weapons research programs. And more than 25 countries are armed with ballistic missiles, hundreds of missile launchers, and thousands of short- and medium-range missiles.<sup>1</sup>

The danger posed by this proliferation prompted a refocusing of the Strategic Defense Initiative Organization in 1993 to defend against shorter range ballistic missiles and protect the U.S. homeland against limited missile attacks. The revised organization, called the Ballistic Missile Defense Organization (BMDO), is now responsible for designing, developing, and acquiring an integrated missile defense for the future. It focuses on three main areas:

■ **Protecting U.S. troops and allies against theater missile attacks:** BMDO's theater missile defense program is designed to protect U.S. forces, allies, and other countries, including areas of vital interest to the United States, from theater missile attacks, or attacks from a relatively short distance (50 to 500 kilometers). Several programs are underway in this area, including the core programs of Theater High Altitude Area Defense (THAAD), Navy Area Defense, and the Patriot Advanced Capabilities (PAC-3).

■ **Protecting the United States from limited ballistic missile attacks:** Although an immediate ballistic missile attack on the United States is unlikely, the possibility of such an attack will increase as Third World countries develop or acquire simple or perhaps even sophisticated ballistic missiles. Therefore, BMDO is pursuing an R&D program to demonstrate the capability of deploying a system to protect the Nation from ballistic missile attacks. The National Missile Defense program will demonstrate a ground-based interceptor; a ground-based radar; and a battle management command, control, and communications system that comprise an initial system.

■ **Investing in advanced technology to counter evolving and proliferating threats:** The Advanced Technology program allows next-generation BMD systems to draw from readily available technology solutions, such as advanced directed energy, sensor, and materials technologies. The program includes Technical Operations (TO), which nurtures high-risk, highly advanced technology. Among many activities, TO also runs the Small Business Innovation Research (SBIR) and Technology Applications programs for BMDO.

### ***The Environmental Industry:***

#### ***Advanced Technology for the Growing Years***

The market for environmental technology is enormous, both in terms of its size today and its potential for growth tomorrow. The industry, nationwide, represents more than 60,000 environmental technology companies and accounts for more than 1 million jobs. Our Nation is presently the international leader; however, its position may change as major competitors position themselves more aggressively in the economic arena. They see a global market, now \$170 bil-

lion, that is expected to more than triple to \$600 billion within the next 12 years.<sup>2</sup>

What are the causes for such pronounced growth in this market? Part of the answer lies with the users, who are beginning to change their attitude about environmental technologies. The environmental industry has long been regarded as an industry driven by regulations—laws and mandates created to protect public health and restore or maintain the condition of natural ecosystems. However, more recently, many industries are beginning to see the economic value of implementing environmental strategies because such activities can improve the efficiencies of existing operations and reduce associated costs in waste. They also see technology's value in improving corporate image because this image can increase the potential for partnerships and sales. In addition, they see that some of the advanced environmental technologies are faster, cheaper, and better than those already in place, and they are therefore more economical when used with, or instead of, current practices. So, domestically, advanced environmental technologies can present economic advantages not only to the technology developers, but also to the users as well, creating a win-win situation for the U.S. economy.

Another issue driving the environmental market is the increased interest internationally in improving environmental quality. Global industrial development is increasing substantially, underscoring the need for pollution prevention, control, and remediation technologies. For example, in 1990, 13 urban areas in the world had populations of 10 million or more. However, experts estimate that in 20 years, there may be 26 of these megacities in place, according to a U.N. medium-growth rate scenario.<sup>3</sup> These huge urban agglomerations face significant environmental problems; however, they also represent a tremendous opportunity for U.S. environmental technology developers, who may then help in environmental

concerns worldwide, while also increasing the economic competitiveness of the United States.

The types of technologies and the problems they address vary significantly in the environmental arena. Diverse technology areas such as photonics, advanced materials, sensors, and directed energy play an important role in addressing society's environmental needs. In this report, these needs are divided into three major categories, which include (1) monitoring and assessment, (2) avoidance, and (3) control and remediation (see page 11).

### ***BMDO's Technology Applications Program: Linking BMDO-funded Technology with U.S. Industries***

BMDO formed the Technology Applications program in 1985 to move BMDO-funded technology to a wide variety of commercial industries. In this way, the Nation and taxpayers alike can benefit through new commercial products, industrial growth, job creation, new businesses, and quality-of-life improvements. The environmental technology industry is one promising area where this federally funded technology can have a positive impact. BMDO has funded a wide spectrum of advanced technologies, while the environmental industry has numerous technology needs due to its diverse and expansive activities.

Highlighting BMDO-funded technologies, this report has been written to inform environmental technology users about new developments that either are, or will be, available. The 15 technologies mentioned in the report are organized into three areas (1) monitoring and assessment, (2) avoidance, and (3) control and remediation. Advances in sensors, photonics, optics, advanced materials, directed energy—first funded for missile defense systems—contribute to these three

areas. Most of the innovations are at least in the prototype stage and several are already on the market.

The incorporation of advanced technology into competitive industries is a forward looking approach; it allows businesses to race miles ahead of competition; it allows the United States to maintain economic competitiveness in a global market; and, in many cases, as often felt in the environmental industry, it improves the quality of life for millions of Americans. To accomplish this, BMDO encourages industry to work with technology developers to move its defense-funded innovations into the private sector. Your interaction with small and large businesses, universities, and Federal laboratories will be essential in accessing advanced technologies mentioned in this report.

We who support the BMDO Technology Applications program welcome the opportunity to exchange information and comments concerning this report. We also offer other publications, such as a quarterly newsletter, free of charge, highlighting technologies that relate to the environmental industry and many other business sectors in the United States. You can contact us at the following address:

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Photo courtesy of Linda Voss.





# Environmental Applications

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Technologies in the report have been organized in the following categories, as indicated at the bottom of each page.

## ■ **Monitoring and Assessment**

These technologies range from remote sensors on satellites to biomarkers on the molecular level and cover land, air, and water resources. The private and public sectors need an abundance of environmental data, using it to determine compliance with regulations, populations of endangered species, and the level of hazardous waste for cleanup activities. Policy makers, for example, need more accurate methods for collecting atmospheric data to make decisions about global warming. Industries need more accurate particulate monitors to accurately measure amounts emitted from smokestacks. Some of the needs that technology can address include lower cost, portability, reliability, and ability to provide data in real or near-real time.

## ■ **Avoidance**

Avoidance technologies alter processes to prevent the production of environmentally hazardous substances. These so-called “green technologies” represent a shift from end-of-pipe pollution control to integration of environmental technology into the production process itself. For example, an industry may implement a pulsed power device to eliminate the growth of zebra mussels on the intake pipes from waterways beside its plant. This “electrotechnology,” or electrically based alternative, avoids the problems associated with chlorine and other chemical treatments, which adversely affect the water source.

## ■ **Control and Remediation**

Control technologies treat hazardous substances to make them harmless before they enter the environment. For example, in industrial plants, advanced technology can decompose pollutants, including emissions such as sulfur dioxide, nitrogen oxides, and volatile organic compounds. Remediation technologies are similar, but treat pollutants after they have left the process. For example, technologies that treat nuclear waste, after it has been generated, would fall into this category.

## Camera Remotely Reveals Hot Spots

### ***Environmental Applications***

Many areas, such as California and the Southwest, are prone to naturally occurring, usually lightning-induced, wildfires, which pose dangers to both the surrounding communities and ecosystems. Most state and local governments have



■ ***The QWIP camera, developed by JPL, can help detect hot spots that may linger after fires are initially extinguished, increasing the safety for firefighters, in forests and urban areas.***

procedures to deal with these fires which, while often devastating and dangerous, are usually expected during dry seasons. The problem is that the danger does not always go away when the fire subsides. Sometimes lingering hot spots, not visible to the human eye, can flare up, thereby starting another battle for the forest services and municipalities to fight. The Jet Propulsion Laboratory's (JPL; Pasadena, CA) quantum well infrared photodetector (QWIP) technology can identify hot spots so firefighters can extinguish them completely.

As an example of its capabilities, a highly sensitive, handheld camera equipped with a focal plane array capable of detecting infrared (IR) radiation debuted as a fire-observing device in Malibu, CA, in October 1996. Using the QWIP camera, a KCAL television news helicopter surveyed the wildfire scene and pinpointed lingering hot spots.

The QWIP camera can also detect infrared patterns of volcanoes, lava tubes, and even the Earth's surface from space. It reveals lava tubes running under apparently stable new lava flows, which could weaken the ground, causing danger to those walking above. It is an improvement over the current detection method of physically inserting sticks into the lava, looking for these structures. The QWIP camera can also read the IR signatures of rocks, especially silicates, and the QWIP structure would also work in satellites. This allows environmentalists to study geologic structures as they relate to flora and fauna populations.

### ***Technical Description***

The 256 x 256 element focal plane array (FPA) camera is based on quantum well infrared photodetector (QWIP) technology. Quantum wells, made of gallium arsenide (GaAs), are at the heart of QWIP IR photodetectors. These structures are sensitive to temperature differences as small as 0.02°Celsius, and their size allows them to be packed to extraordinary densities. This packing improves the QWIPs' efficiency. Compared with other photodetectors, GaAs-based QWIPs are easier to manufacture and, as the technology matures, they should eventually cost less to build.

Nationally, in the past 10 years, an average of nearly 73,000 wildfires have burned more than three million acres of Federal and state lands each year. These fires have destroyed or damaged millions of acres of commercial timber, livestock forage, and wildlife habitat that will take many years to recover. In addition, with more and more people building primary and secondary homes adjacent to, or intermingled with, the wildlands, dozens—sometimes hundreds—of homes and other structures are lost to wildfire each year. And, resource and property losses aside, many firefighters lose their lives each year in the battle against wildfires.

The QWIP camera's ability to identify hot spots can help firefighters monitor controlled burns as well as help them strategically fight fires that become a threat to people and their property in nearby residential communities.

### ***Environmental Benefit***

Throughout much of this century, North American natural resource management's philosophy concerning fire has been one of fire suppression, especially since we have become steadily more skilled at stopping unwanted fires using new techniques and technologies, such as aerial firefighting technology. However, this philosophy is changing to one of con-

Photo courtesy of Cherie Doyle.



trolled burns and fire management when in a natural environment. As long ago as the 1940s, the U.S. Forest Service began allowing some wildfires to burn. The benefits of allowing some natural change to take place include increased diversity of plant and wildlife habitats and renewed and invigorated forests from nutrients released in the ashes<sup>4</sup>. But these fires, like all fires, must be carefully watched to make sure that people and their property are not endangered.

#### **Product Status**

JPL, in conjunction with Raytheon (previously Amber; Goleta, CA) and Inframetrics (Billerica, MA), developed QWIP cameras based on JPL's QWIP technology, Amber's 256 x 256-element AE166 readout multiplexer, and Inframetrics' and Amber's camera platform. The camera uses a highly sensitive, low-dark-current, 9.0-micrometer 256 x 256 element QWIP FPA that operates at or above 70 kelvin.

JPL has also successfully demonstrated other IR cameras that use QWIP FPAs. The first camera uses a 128 x 128 element array for space-based imaging in the 15-micrometer

IR region at 45K. The second camera uses a 256 x 256-element array for ground-based imaging of space objects and space-based imaging in the 8- to 9-micrometer IR region at 70K. JPL has recently demonstrated a 640 x 486-element FPA, which provides television-like high-resolution images in long-wavelength IR.

#### **BMDO Origin**

With funding from BMDO's Innovative Science and Technology Program, JPL is developing long wavelength IR imaging cameras for ground-based and space-based applications. These cameras have the sensitivity to detect even cold objects, such as ballistic missiles in midcourse flight when the engine is not burning.

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## Monitor Images and Identifies Stack Pollutants From Afar

### *Environmental Applications*

In an effort to control pollution, industries are monitoring emissions from their smokestacks to ensure that their control mechanisms are operating properly and their plants are not emitting undesirable levels of pollutants. They may be taking these measures to preserve the environment, protect human health, and increase plant efficiencies. However, they are also taking these measures because they have to—because it is the law. In the 1960s, public outcry about growing air pollution problems resounded throughout the

halls of Congress and state agencies, resulting in strict Federal and state regulations. For example, the Clean Air Act of 1963, amended in 1967, 1970, 1977, and 1990, regulates the emissions of several air polluting substances such as sulfur dioxide ( $\text{SO}_2$ ) and nitrogen oxides ( $\text{NO}_x$ ) from specified industrial plants.

For years, to monitor emissions, industry workers hand-sampled emissions and analyzed them at laboratories; and, in some cases, industries are still using this practice. However, this approach is slow, cumbersome, and involves workers who are exposed to the sampled pollutants. New technological breakthroughs over the present decade have swayed industry in a new direction; allowing industries to easily collect and accurately read emissions in near real time with reduced exposure to workers.

### *Technical Description*

Pacific Advanced Technology, Inc. (PAT; Santa Ynez, CA), has developed an imaging spectroradiometer that can be used

to detect and identify chemicals for environmental applications. Called the image multispectral sensor (IMSS), this technology is based on advances in diffractive optics and image signal processing. It images a scene in three dimensions—two spatial and one spectral—to build a multispectral spatial imaging cube of data.

While other spectral imaging devices have very complex optics and require exact alignment, PAT's instrument uses a simple optical design that allows for relaxed tolerances on optical alignment. Rugged and portable, it can operate in harsh environments such as airborne and space-based platforms. The IMSS has a wavelength resolution of 1 part in about 400.

PAT has commercialized this instrument with joint funding from the BMDO SBIR program and Raytheon (previously Amber; Goleta, CA). Raytheon sells the commercial IMSS as an attachment to its RADIANCE 1™ camera to make a midwave infrared multispectral radiometric imager, useful for spectroscopy and radiometry. PAT supplies Raytheon with the IMSS as well as the image and signal processing software called HYPAT. This system uses an  $f/2$  nominal lens with a 104-millimeter focal length and covers the full 3- to 5-micrometer spectral band with a spectral resolution of better than 0.01 micrometer. In the highest data acquisition mode, HYPAT collects images from 3 to 5 micrometers into 200 spectral bins in less than 1 second.

### *Environmental Benefit*

As one of these new monitoring technologies, PAT's remote IMSS system addresses industries' issues. It allows industrial plants to identify and quantify chemicals emitted from smokestacks from a distance away from the site thereby minimizing emissions exposure to workers. In addition,



■ Pacific Advanced Technology's IMSS, when attached to an infrared camera, visually allows industrial plants to identify and quantify chemicals emitted from their smokestacks.

Photo courtesy of John Kennedy



environmental officials can likewise benefit from the IMSS's same features, and are able to use it as an enforcement tool to confirm that industry is complying with Federal, state, and local regulations.

#### **Product Status**

The PAT IMSS lens and HYPAT software is sold by PAT as an accessory to the Raytheon infrared camera, making it a mid-infrared, multispectral radiometric imager useful for spectroscopy and radiometry.

PAT and Raytheon have paired the IMSS lens with the RADIANCE 1 camera to remotely monitor smokestack emissions. They have successfully demonstrated their combined system in the field, detecting carbon monoxide (CO) and carbon dioxide (CO<sub>2</sub>) emissions from two separate smokestacks at an oil refinery—more than 1 km away. PAT is also interested in demonstrating detection of sulfur dioxide (SO<sub>2</sub>) and nitrogen oxides (NO<sub>x</sub>).

#### **BMDO Origin**

BMDO funded PAT through SBIR Phase I and II contracts for theater missile defense. The IMSS technology can detect missiles in clutter, identify friend or foe signatures, perform kill assessment, and detect and identify chemical agents.

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## Smog Dog Identifies Air Polluters Driving Down the Road

### ***Environmental Applications***

Air pollution is big business but for the wrong reasons—it makes us sick and drains our pocketbooks. According to the American Lung Association, even small reductions in air pollution save tens of millions of dollars associated with hospital stays, emergency room visits, time off from work and school, and premature death. The Association estimates that the Clean Air Act resulted in \$23 trillion in health benefits from 1970 to 1990.<sup>5</sup>

Motor vehicles emit several pollutants that the Environmental Protection Agency (EPA) classifies as known or probable human carcinogens, including benzene; formaldehyde; acetaldehyde; 1,3-butadiene; and diesel particulates. Most of these hydrocarbons are released or formed as a result of incomplete combustion in the engine. EPA estimates that mobile sources of air toxins, such as cars, trucks, and buses, account for as much as half of all cancers attributed to outdoor sources of air toxics.<sup>6</sup> Another pollutant attracting attention because of its adverse health effects is lower-atmospheric ozone, a secondary pollutant that results from reactions between oxygen and primary pollutants, such as those listed above, and yields smog.

Today's vehicles, with their on-board computers and catalytic converters, can emit 90-percent less of these air toxics per mile than the models that were uncontrolled before passage of the Clean Air Act in 1970.<sup>7</sup> If a vehicle pollutes more than allowed for its size and model, there is a good chance that the engine has a mechanical problem. By identifying this vehicle and notifying its owner, the problem can be corrected.



■ *Smog Dog, pictured above, sits on the side of the road and analyzes the exhaust plumes of vehicles as they pass by. It has been made available to many states for remote monitoring.*

### ***Technical Description***

Smog Dog<sup>®</sup> is a mobile, remote emissions sensor system that characterizes vehicle exhaust. The system consists of a sensor head, infrared (IR) source, video camera, and electronics. The electronics capture, display, and store both image data (such as license plates) and automobile emissions data. Smog Dog can function as a stand-alone system or be incorporated into a van for mobility.

To implement the system, SmogDog's IR source is placed on one side of the road to direct a beam across traffic to a sensor on the other side. As the vehicle passes by, changes in the IR beam's intensity yield the relative concentrations of carbon monoxide (CO), carbon dioxide (CO<sub>2</sub>), hydrocarbons, and nitrogen oxides (NO<sub>x</sub>) in the emissions. Simultaneously, a roadside camera snaps a video shot of the vehicle. A computer in the van reads the exhaust gas concentrations and the license plate. Each day, the system downloads its data into state computers, matching the information with automobile registrations and singling out automobiles polluting more than allowed for their size and model year.

The sensor head is based on unique heterojunction interface trap (HIT) detectors, which perform better than traditional photoconductive detectors because their p-junction structure is underneath the standard n-photoconductive layer. This p-layer is formed in a region of the device that has a wider electrical bandgap. The p-layer traps minority carrier holes and maximizes the life of the photosignal. Concurrently, the width of the n-layer is increased, allowing more device gain. This high gain of the HIT detectors allows operation at much lower bias power, yet maintains the photon noise level above the noise level of standard preamplifiers, thus giving sensitivity limited by IR background. The HIT detectors adapted for use in Smog Dog operate in the 3- to 5- micrometer range at 200 Kelvin (or -73° C) with thermoelectric coolers.



Photo courtesy of Cherie Doyle.



### ***Environmental Benefit***

Using Smog Dog to monitor vehicle exhaust and identify the excessive polluters can provide the data needed for enforcement officials to remove these vehicles from our highways. By doing so, air pollution can be reduced (and air quality enhanced) to provide a healthier environment.

### ***Product Status***

Santa Barbara Research Center (SBRC; Goleta, CA) sold dozens of Smog Dog units to customers both in the United States and abroad. Many states, such as Arizona, California, Idaho, Utah, New Mexico, Alaska, Virginia, and Rhode Island, have purchased services or equipment to perform remote sensing of vehicle emissions; Arizona is the first state to employ remote sensing as a continuing program to reduce automotive pollution. International customers have included Canada, Australia, Sweden, and Taiwan.

Envirotest Systems (Sunnyvale, CA) recently purchased the Smog Dog product line from SBRC. Its subsidiary,

Remote Sensing Technologies Inc., will continue to develop and market Smog Dog products for remote sensing of vehicle emissions.

### ***BMDO Origin***

BMDO sponsored the HIT program for which SBRC developed the infrared detectors. One of the HIT program's goals was to extend the operating wavelength of IR imaging sensors. Extending the operating wavelength also increased the sensitivity and operating temperature and improved the manufacturing yield of mercury cadmium telluride IR detectors. All of these developments improved IR linear sensor array technology for ballistic missile surveillance and tracking.

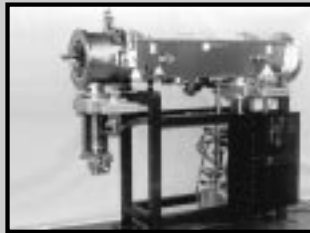
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## System Identifies Contents of Underground Storage Tanks

### ***Environmental Applications***

In large environmental remediation projects at weapons facilities, clean-up crews could greatly benefit from identification techniques when handling and disposing of radioactive waste. Long before realizing the potential danger of radioactive waste, people stored it in inadequate underground storage tanks (USTs) or through other similar means. Proper disposal has become a grave issue because USTs can pit or crack, allowing their contents to seep into ground water and travel many miles from the site. The contents then can threaten drinking and recreational water supplies as well as various ecosystems.



■ ***Pictured above is AccSys' RFQ linac. The table-top sized accelerator is compact and low cost enough to be used for characterization of nuclear waste.***

Over the past two decades, scientists have become much more concerned about the condition of storage sites. To remediate the situation, various government and commercial organizations have spent a significant amount of money for clean-up activities. But this effort has not been easy. The handling and disposal of radioactive wastes varies, as do the associated costs, depending on the level of radioactivity, and the technology for making such determinations has been limited. To illustrate the complexity of the problem, there are five categories of nuclear waste, each of which must be treated differently.

To make matters even more complicated, conventional garbage and other less-toxic material have also been contained in unmarked USTs and thrown in the same pit with the hazardous waste. While this material can be dealt with much more easily and usually at a much lower cost, it has been difficult to make the differentiation, and crews have been forced to take a more conservative and therefore more costly approach.

### ***Technical Description***

Addressing this problem, AccSys Technology, Inc. (Pleasanton, CA), has developed a Radio Frequency Quadrupole linear accelerator (RFQ linac) specifically tailored for use in a nondestructive evaluation technique. This technology can analyze and differentiate between different types of hazardous and nonhazardous wastes noninvasively and onsite. Small enough to fit on a tabletop, the accelerator is much smaller than direct current and Van de Graaff accelerators because it integrates various functions that previously required several stages. The RFQ linac uses electromagnetic fields to bunch and accelerate an incoming stream of ions to speeds of up to 17,000 miles per second. The system is lighter because it does not need bulk shielding. (The accelerated particles that produce neutrons do not create radioactive hazards.)

The RFQ linac is well-suited for spectrographic analysis, particularly gamma spectroscopy, neutron radiography, and neutron activation analysis. In gamma spectroscopy, objects emit gamma rays when bombarded with neutrons. Different materials emit distinctive gamma rays, depending on their elemental composition. For example, nitrogen absorbs low-energy neutrons and emits a characteristic, easily identifiable gamma ray. This principle allows the user to identify an object's composition and trace elements by comparing gamma ray energies to values obtained from known elements.

Unlike gamma spectroscopy, neutron radiography can identify different materials based on the absorption spectrum of neutrons. Although neutron radiography was first introduced in 1948, and tomographic imaging was attempted in 1977 after introduction of the computed tomography (CT) scan, two factors have limited the introduction of neutron

Photo courtesy of Renan Kiper.



transmission imaging into routine practice: (1) unavailability of intense neutron sources other than large reactors, and (2) limitation of positron-sensitive neutron detector technology. The RFQ linac supplies the needed intense neutron source in a compact, portable package.

Neutron activation analysis involves bombarding a sample with neutrons so that it emits a characteristic radiation including, but not limited to, gamma radiation. The emitted radiation is then analyzed. This works for mineral or petroleum sample analysis and testing radioactive waste material.

### ***Environmental Benefit***

The compact RFQ linac's ability to identify and analyze the contents of storage tanks on a waste site presents three key advantages for remediation activities. First, the technology saves costs and time associated with overconservative handling and disposal measures. Such savings can be significant, especially when weighing the difference between

the handling and disposal of garbage and that of high-level nuclear waste. Second, the RFQ linac allows technicians to do their jobs more efficiently, reducing labor costs and increasing the speed that sites are remediated. Third, the technology reduces occupational hazards to clean up crews and the public, since nondestructive evaluation can be performed onsite.

### ***Product Status***

AccSys Technology's RFQ linac comes in several models with ion beam energies ranging from 1 MeV to 4 MeV. Oak Ridge National Laboratory is currently using an AccSys RFQ linac in a feasibility study for a linac-based transuranic waste characterization system.

### ***BMDO Origin***

The RFQ linac was first conceived by Soviet scientists in 1970. Los Alamos National Laboratory (LANL) later conduct-

ed a proof-of-principle demonstration of the RFQ linac in 1980, the first outside the Soviet Union. Because of the RFQ linac's potential as a directed energy weapon, BMDO (then the Strategic Defense Initiative Organization) assumed partial support for LANL's work in 1984. Several LANL scientists left in

#### **The Five Levels of Nuclear Waste**

- Spent nuclear fuel and high-level waste
- Transuranic wastes, which are man-made elements heavier than uranium
- Uranium mill tailings
- Low-level waste
- Naturally occurring and accelerator-generated waste

1985 and founded AccSys to design and build RFQ linacs. AccSys quickly received SBIR contracts from several government agencies, including BMDO. The contracts were for areas as diverse as medicine, directed energy weapons, non-destructive materials inspection, and high-energy physics research in the Superconducting Super Collider (SSC) program. AccSys also built and tested the various components

of a larger accelerator through these SBIR contracts, including ion generators, an RFQ linac and amplifier, and a drift tube linac and amplifier.

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Photo courtesy of Lisa Hylton.



## System Gives a Better Read on Particulate Emissions

### **Environmental Applications**

Although studied as early as the 1950's, air pollution from particulate emissions has just recently become an elevated issue for regulators in the United States and worldwide. Today's concern is due in part to epidemiological studies,

which suggest that air borne particulates at levels even lower than current standards can have a negative impact on morbidity and mortality rates.

Therefore, the Environmental Protection Agency has established relatively new performance specifications (PS-11) mandating that certain industries continuously monitor emissions of particulates. Newly proposed regulations will require the use of previously nonexistent monitors, first on hazardous waste combustors (see 61 Federal Register 17358, April 19, 1996) and then on other sources in the near future.

### **Technical Description**

Environmental Systems Corporation (ESC; Knoxville, TN) has developed a continuous emissions monitor for particulates that can measure particle densities of less than 100 micrograms per cubic centimeter. The device can also monitor pipelines, stacks, venting systems, and other emissions sites.

The company's system is an optical device that detects and measures light scattered from particulates that are illuminated as they pass through a low-power laser beam. One of the challenges to developing the system was in designing optics that could be mass produced. To achieve this goal, ESC tapped into the expertise of the Ultraprecision Manufacturing Technology Center (UMTC; Oak Ridge, TN). Through its single-point diamond turning capabilities, the UMTC helped

the ESC develop new techniques that will allow the company to produce hundreds of monitors per year.

The single point diamond turning machinery at UMTC fabricates complex aspheric shapes for optics using natural or synthetic diamond tools, which can produce ultra smooth surfaces much faster than other polishing methods. The manufacturing cell can produce diffraction-limited optics at visible wavelengths with low surface scatter in a variety of materials, including aluminum, copper, plastics, and infrared crystal materials.

### **Environmental Benefit**

ESC's monitors are projected to cost between \$12,000 and \$15,000, which compares well with competing monitors, which cost between \$18,000 and \$20,000. They will also perform better, with higher precision, than competing technology. It will allow users to meet the proposed PS-11 mandate.

### **Product Status**

ESC entered a cooperative research and development agreement (CRADA) with UMTC, which has since ended. ESC and the U.S. Department of Energy each provided \$50,000 toward the CRADA (totaling \$100,000). ESC and Oak Ridge National Laboratory have filed for a joint patent.

In mid-1998, ESC will replace its existing model P-5A with a new monitor based on the technology resulting from the CRADA. The systems will be sold through the company's products and systems division.

### **BMDO Origin**

UMTC was previously called the Optics Manufacturing Operations Development and Integration Laboratory (MODIL), which was funded by BMDO in the early 1990s.



■ *Cheaper and more accurate than current technology, ESC's particulate monitor, pictured above, should address some of the new concerns raised by state and local governments about particulate emissions from power plants.*

Photo courtesy of Lisa Hylton.



The Optics MODIL was one of four facilities BMDO set up to help industry decrease the cost, increase the quality, and speed the manufacture of ballistic missile defense systems. The MODIL provided testing facilities and new equipment for emerging technologies to lower industry's investment risk.

Originally, the mission of the Optics MODIL was to develop and validate the manufacture of such high-precision telescope components as mirrors, windows, lenses, and baffles. BMDO (then the Strategic Defense Initiative Organization) considered these components fundamental to its program because they contributed to the early detection of and defense against missile launches.

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## Predicting Where Underground Contaminants Go

### **Environmental Applications**

Prediction of environmental contamination must be more than just a lucky guess. It is important because today's groundwater contaminants at remote locations can leach into aquifers, presenting themselves miles away in

tomorrow's drinking water. Ground water contamination has become an especially plaguing problem at our Nation's weapons facilities. Highly toxic materials for weapons manufacturing and chlorinated hydrocarbons for equipment cleaning have posed costly cleanup questions for environmental engineers: Where will contaminants end up next? How extensive could the environmen-

tal impact be? The answers can help engineers determine the extent and strategy for effective remediation.

Coleman Research Corporation (CRC; Fairfax, VA) has developed a predictive modeling technique called data fusion modeling (DFM), which can help answer these questions in advance. This computational technology combines complex, dissimilar data to provide 3-D predictive subsurface simulated models. Especially useful for modeling geologic and hydrogeologic features, DFM can support risk assessment and remediation planning. It can also provide real-time updates during remediation and site investigations.

CRC has used data fusion modeling at three U.S. Department of Energy sites: Hanford Site 200 West Area (Richland, WA), Pantex Facility Site (Amarillo, TX), and Savannah River Site (Aiken, SC). At the Hanford Site, DFM determined the distribution of contaminants, particularly

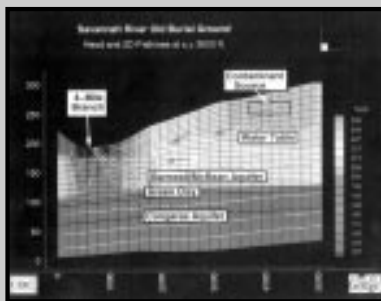
plutonium, relative to geological features. Data fusion combined different types of data collected from various sources and quantified geologic uncertainties present in the terrain. At the Pantex Site, DFM determined the flow pathlines in a perched aquifer above the fine-grained zone aquitard. The goal was to determine potential contaminant pathways into the Ogallala groundwater aquifer. At the Savannah River Site, DFM was used at the Old Burial Ground, the original burial place for solid, radioactive, and hazardous waste for the Savannah River Site General Separations Area. Solid waste was deposited at the Old Burial Ground from 1952 to 1972. The data fusion model addressed tritium migration from the old burial ground, and the data were then compared with an existing flow and transport model. The two models yielded similar pathlines, but the data fusion model fit the source data better and provided improved stream flow prediction and quantification of geologic uncertainties.

### **Technical Description**

Most automated prediction and control systems receive and compare sensor information from numerous sources. DFM incorporates a square root information filter (SRIF) algorithm, which eliminates redundant data. In doing so, the algorithm reduces the number of calculations, lessening computational demands. The software combines a priori knowledge with data from sensors. So, this powerful model only needs a Unix workstation or high-end personal computer to perform tasks that normally would require a supercomputer.

### **Environmental Benefit**

Using DFM along with sensor input can help hydrogeologists and environmental engineers determine the extent and directional movement of the subterranean contamination plume. Then, armed with this information and predictive



■ **At the Hanford Site, Coleman Research's DFM determined the distribution of contaminants, particularly plutonium, relative to geological features.**



Photo courtesy of Cigdem Cencer.



modeling, they can use precisely drilled wells to monitor contaminants. Skillfully planned and located monitoring wells allow planners to tap into the available monitoring and technical resources efficiently and effectively. The model's predictive capability also increases the time available to alert nearby communities whose drinking water may be compromised or to intercept or remove the contamination.

#### ***Product Status***

CRC is marketing its DFM services for the applications mentioned above. Examples of the 3-D data fusion model are available on its Internet site at <http://www.crc.com/df/p1.htm>.

#### ***BMDO Origin***

The SRIF algorithm was developed by Computational Engineering, Inc., which was purchased by Coleman. Computational Engineering received BMDO SBIR contracts for algorithms to track ballistic missile targets and decoys.

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## POAM Monitors Provide New Leads About the Ozone

### *Environmental Applications*

Climate change can destroy crops; flood farmland, cities, and coasts; and spread epidemics. It can intensify storms, obliterate fisheries, and promote skin cancer and cataracts. It can lead to massive economic dislocations, waves of refugees, and other political instability. As a result, assessment of climate change has become central to many policy decisions.

Policy makers will need better monitoring equipment so that they can fully understand climate and contributing factors when making regulatory decisions.

Many factors affect climate change. The relationship of the ozone layer, aerosols, and high-altitude clouds has an affect. Additionally, the increasing amount of atmospheric gases can trap heat radiation in the lower atmosphere—a condition commonly

referred to as global warming. Therefore, monitoring stratospheric ozone, aerosols, and high clouds is an important aspect in evaluating atmospheric change.

For example, by monitoring the wintertime polar stratospheric vortex, scientists and policy makers may be able to understand climate change and the ozone layer better. The polar stratospheric vortex plays a pivotal role in intensifying ozone depletion in the polar regions and favors the formation of polar stratospheric clouds (PSCs). Chemical reactions on the surfaces of the PSC particles then convert chlorine ( $\text{Cl}_2$ ), generated by human activity, into different forms that destroy ozone during the polar spring when sunlight returns to the region.

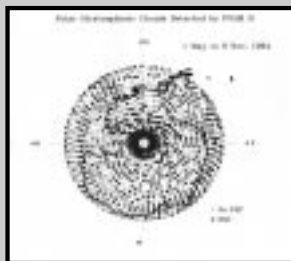
Understanding the activity of polar mesospheric clouds (PMCs) may also provide glimpses into conditions related to climate change. PMCs are unusual and still somewhat myste-

rious clouds that occur only at the polar regions. They occur much higher (about 83 kilometers) than other types of clouds and only during a few midsummer weeks. PMCs are known as noctilucent clouds and are believed to consist of ice nucleated on meteor dust. They may indicate climate change, since changes in the greenhouse balance that would warm the lower atmosphere would also cool the upper atmosphere, promoting the occurrence of PMCs.

### *Technical Description*

Funded by BMDO through the Naval Research Laboratory, ThermoTrex Corporation (San Diego, CA) developed a monitoring device called Polar Ozone and Aerosol Measurement (POAM) II, which has provided unique monitoring data related not only to ballistic missile defense, but to environmental conditions as well. It was launched in October 1993 and gathered data about stratospheric ozone, aerosols, and high clouds until its mission ended in November 1996. POAM II was carried by SPOT-3, a satellite in the French Satellite Pour l'Observation de la Terre (SPOT) series.

POAM II measured ozone, aerosols, and other atmospheric properties by determining the changing intensity of received sunlight as the instrument watches the sun rise and set through the Earth's atmosphere. The wavelengths measured by POAM II span the near ultraviolet (UV), visible, and near infrared portions of the spectrum, from 352 to 1,060 nanometers. In POAM II's polar Sun-synchronous orbit, there are one sunrise and one sunset per orbit, producing a total of 14 sunrises and 14 sunsets per day. POAM II measures the changing intensity of sunlight at nine wavelengths, so that the reductions in intensity due to ozone ( $\text{O}_3$ ), nitrogen dioxide ( $\text{NO}_2$ ), water vapor ( $\text{H}_2\text{O}$ ), aerosols, clouds, and the bulk atmospheric density can be disentangled.



■ POAM II data have been used to measure the rate of ozone depletion in the southern and northern hemispheres. Pictured above is an image developed based on data obtained.

Photo courtesy of Lisa Hylton.



POAM III, an offshoot of POAM II, is in a near-polar, sun-synchronous orbit on a French SPOT satellite (thus extending POAM II's coverage in time) and builds on lessons learned from POAM II. Improvements include greater sensitivity at UV wavelengths, improved filters, less stray light, adjustable amplification factors, improved blackening methods, and a wide-angle sun sensor as well as the narrow-angle sun sensor used in POAM II. Improved blackening methods help eliminate potential hydrocarbons that outgas in the instrument itself. Adjustable gains compensate for sun-polymerized hydrocarbon films that may form on the optics from spacecraft outgassing.

#### ***Environmental Benefit***

POAM II data have helped in the assessment of climate change both by increasing our knowledge of the physical nature of the atmosphere and allowing comparisons to climate models. Thus, POAM II is helping to support the policy decisions related to climate change and its overall impact.

For example, POAM II has provided information on the permeability of the wintertime polar stratospheric vortex as a function of altitude and time and has provided a wealth of data on PSCs, including detailed statistics on when and where they occur. Its multiwavelength sensor capabilities allow scientists to measure the surface area of the cloud particles per unit volume of air. This data measures a cloud's ability to activate chlorine.

In addition, POAM II data have been used to measure the rate of ozone depletion in the Southern and Northern Hemispheres because the mechanisms dominating the depletion of ozone differ somewhat by hemisphere. These results have highlighted deficiencies in present photochemical models of ozone depletion. POAM II measurements have contributed significantly to our knowledge of seasonal and latitudinal variations in the stratospheric aerosol burden and in the distribution of  $\text{NO}_2$ , a gas that plays an important role in setting ozone concentrations.

POAM II also provided the first measurements of optical extinction by PMCs. Previously, only scattered radiation from PMCs had been measured. Measurements of extinction complement those of scattering and are somewhat easier to compare with models of the cloud particles. POAM II's multi-wavelength measurements made it possible to define the PMC particle size boundaries, effectively giving researchers limits on these particle sizes. POAM's measurements of PMCs are being combined with earlier measurements to provide data on trends in their frequency of occurrence and intensity.

The follow-on instrument POAM III will enhance the payoffs from POAM II. In monitoring climate, it is essential to disentangle variations from long-term trends. The most effective tools for this difficult task are a series of measurements extending over many years, taken by instruments whose measurements can readily be compared, so that changes from instrument to instrument cannot be mistaken for long-term trends in atmospheric behavior. POAM III is sufficiently similar to POAM II to allow accurate comparisons of measurements from the two instruments. Thus POAM III together with POAM II will produce the type of long-term data set most useful in searching for climate trends.

### ***Product Status***

The POAM II mission was interrupted by the failure of the SPOT-3 host satellite in November 1996; however, the Naval Research Laboratory (NRL; Washington, DC) freely distributes POAM II data. POAM III, which is designed to last five years, has been integrated onto the SPOT-4 satellite launched in March 1998.

### ***BMDO Origin***

BMDO's Innovative Science and Technology Program funded the fabrication of POAM II, which was originally designed to measure atmospheric properties for laser propagation at wavelengths of 353 and 1,059 nm. It was interested in atmospheric properties because stratospheric aerosols and subvisual clouds significantly affect long-path laser propagation. The NRL, through the Office of Naval Research (ONR), later funded and redesigned POAM II to make it suitable for a broader spectrum of atmospheric measurements. Like POAM II, POAM III was built by ThermoTrex, which reused and slightly modified the POAM II ground support and test equipment.

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Photo courtesy of NASA.





## MSX Provides Valuable Data for Ecologists

### ***Environmental Applications***

Without understanding the environmental impact of mankind's activities from a global perspective, it is very difficult for policy makers, scientists, and industry leaders to make sound decisions that will protect our planet's ecosystems. The BMDO-funded Midcourse Space Experiment (MSX) satellite is a remote hyperspectral monitoring system that can help these groups with their analysis. It measures signatures rang-



■ ***MSX, illustrated above, is supplying data about various environmental conditions so that industries, policy makers, and scientists will have more in-depth knowledge about climatic changes, such as flood predictions.***

ing from the far ultraviolet (UV; 0.1 micrometers) to the long-wavelength infrared (IR; 28 micrometers), and can therefore detect trace gases such as ozone ( $O_3$ ), nitric oxide (NO), and nitrogen dioxide ( $NO_2$ ). Data from MSX could increase knowledge of the dynamic processes occurring on the Earth's surface, its oceans, and in the troposphere. This understanding could help scientists

predict natural phenomena influenced by climactic change, such as floods, droughts, and severe winters. To this end, scientists have begun exploring possible environmental uses for the satellite and its sensors.

For example, MSX may help scientists quantify the distribution of ozone in the Earth's atmosphere. Scientists have known for decades that too much ozone in the troposphere, the lowest level of the atmosphere, leads to photochemical smog; and too little ozone higher in the stratosphere allows excessive UV light to reach the Earth's surface, potentially leading to increased skin cancer rates and lower agricultural productivity. Scientists have not known, however, exactly how much ozone is in the various altitudes of the atmosphere throughout the world, unable to obtain good readings from space. Therefore, researchers at The Johns Hopkins University Applied Physics Laboratory (APL; Laurel, MD) are

using MSX to demonstrate an ozone measurement technique called stellar occultation to obtain altitude distribution readings of ozone. In stellar occultation, scientists point MSX at a star, which is held locked in the instrument's field of view as the spacecraft moves through its orbit. As MSX orbits, from its perspective, the star appears to set through the atmosphere. Using the star's light as a standard candle, the amount and distribution of absorption of the starlight by the atmosphere can be determined. From this technique, the altitude-dependent distribution of ozone can be determined. MSX is ideal for this technique because it has a hyperspectral imager, a very steady platform, and accurate pointing and tracking capabilities.

In another example, MSX can assess the health of an ocean by measuring its color (affected by the productivity of phytoplankton) and bioluminescence (light generated from small living sea creatures). As future missions are planned to examine the details of the littoral, or coastal, region of the oceans, it will be useful to know the complex spectral signature of these waters. Most sensors have been used to understand the distribution of chlorophyll in Earth's deep oceans. The number of "colors" (or spectral bands) required for that measurement is low, only four to eight. Once suspended sediments and organic matter, as well as continental aerosols, are added to the mix, the problem becomes much more complex and many more spectral bands are required. MSX's dynamic range makes it more suitable for these advanced applications.

### ***Technical Description***

MSX is a hyperspectral sensing spacecraft. It can be activated on command to swing around and focus on an event. All data collection events are characterized by the transition from a spacecraft safe state ("park") to an active data collec-

Photo courtesy of Ferhan Kiper-Doyle.



tion mode, which may involve complex maneuvering, and then the transition back to park. This procedure is quite different from most environmental satellites, which are constantly on, pointing toward Earth, and whose viewing angle is relatively limited. MSX's event-driven ability can be a great advantage when used to collect focused data for which detailed ground-based characterizations have been performed ("ground truth"). This focused data set can then be used to inexpensively validate future sensor designs.

MSX remains the first and only hyperspectral imaging system in orbit. In a typical panchromatic imager, light from a broad range of wavelengths (for example, all visible light) forms the image. In a multispectral imager, light from a few broad bands (for example, red, blue, and green), can be used to form an image. In a hyperspectral imaging system, spatial pictures are obtained at dozens or hundreds of discrete wavelength bands. Since the chemistry, biology, or physics of a phenomenon is often reflected in its detailed spectrum,

hyperspectral imaging provides new data for researchers involved in studying the Earth's complex interactions—a new window on our world.

Two MSX instruments are useful in environmental applications: (1) the Ultraviolet and Visible Imagers and Spectrographic Imagers (UVISI), which is a hyperspectral imaging system, and (2) the Spatial Infrared Imaging Telescope (SPIRIT III), which is an infrared radiometer and interferometer. The UVISI system combines a set of multispectral imagers with an array of hyperspectral imagers. It breaks the observed spectrum into 1,350 "colors." This hyperspectral capability enables MSX to observe the signatures of important trace constituents (see box on page 32).

BMDO mission requirements dictated the unique capability of multi-angle viewing. In multi-angle viewing, a spot on the ground or in space is held within the field of view of the MSX instruments as the spacecraft speeds along its orbit at 7 kilometers per second (15,000 miles per hour). This abil-



ity to observe atmospheric or terrestrial emissions over a range of Sun and observer angles is unique.

### **Environmental Benefit**

MSX can be leveraged as a testbed for DOD and environmental remote sensing systems, thereby saving costs associated with research, development, and launch of customized satellite-systems. For example, NASA can save millions of dollars on stellar occultation by using an existing space asset to prove the concept.

#### **SAMPLE TRACE GASES THAT MSX CAN DETECT**

- ozone (O<sub>3</sub>)
- nitric oxide (NO)
- nitrogen dioxide (NO<sub>2</sub>)
- sulfur dioxide (SO<sub>2</sub>)
- chlorine dioxide (ClO<sub>2</sub>)
- chlorine monoxide (ClO)
- bromine oxide (BrO)

In addition, data obtained from the MSX satellite could raise the awareness of various environmental conditions so that industries, policy makers, and scientists can take action before problems escalate to catastrophic levels. For example, as previously discussed, increased knowledge of the dynamic processes on Earth and in its atmosphere may result in more accurate prediction of natural phenomena, such as floods. These predictions can help municipalities, farmers, and others take preventative actions, potentially saving lives and valuable resources. In

addition, the data can help policy makers enact appropriate environmental regulations.

### **Product Status**

On April 24, 1996, MSX was launched into an orbit chosen to provide observations of ballistic missile trajectories under sunlit and dark conditions. The infrared instrument (SPIRIT III) was cooled by a block of solid hydrogen. In early February 1997, the cryogen expired. Since that time, missile launches, resident space objects, and other targets of interest to DOD have been observed by the remaining sensors (UVISI and the space-based visible instruments). Because MSX was

designed to be free of all consumables (other than solid hydrogen), the system is expected to last at least another four years. With the end of cryogen operations, BMDO has scaled back its requirements for MSX data collection events, thus freeing time for other potential users and helping to provide the best return for taxpayer money during the spacecraft's remaining life.

BMDO signed a data-sharing memorandum of agreement with NASA in January 1995, and NASA scientists are evaluating MSX data. Such data could provide unique insights into a wide range of geophysical phenomena in support of planned Mission to Planet Earth (MTPE) experiments. The first MTPE Earth Observing System satellite is scheduled to launch in late 1998.

In addition, scientists at APL, NASA, and the U.S. Department of Energy Atmospheric Radiation Monitoring Program are using MSX data to study the three-dimensional structure of clouds and the distribution and composition of atmospheric aerosols.

### **BMDO Origin**

BMDO funded development of MSX to characterize missile signatures during midcourse flight against various spatial backgrounds. At 17 feet and 6,200 pounds, MSX is the largest spacecraft APL has built. APL integrated the efforts of more than 30 organizations, built the UVISI instrument, and manages the mission. Utah State University's Space Dynamics Laboratory (Logan, UT) built the SPIRIT III instruments.

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Photo courtesy of NASA.



## Online Monitor Helps Manufacturers Reduce Waste

### ***Environmental Applications***

In an idealistic world, the best way to address pollution is not to generate it at all. Avoidance technologies increase efficiencies or alter processes to reduce the amount of pollution produced. When less pollution is generated during production, less must be treated or disposed of at the end of the process.

One type of avoidance technology is a quality assurance spectrometer using an acousto-optic tunable filter (AOTF). When used for near-infrared (NIR) spectroscopy, AOTFs can monitor processes in near-real time, replacing the need for wet chemical analysis.

With wet chemical analysis, a person must hand-sample the material and bring it to a laboratory, where it is analyzed. This process is relatively time consuming, so, in most cases, chemical manufacturers will not be able to monitor every bit of their product. Rather, they only take random samples in batches every so often. If the random sample coming off the processing line is of poor quality, then the entire batch is often considered unacceptable and is discarded.

With AOTF-based spectrometers, manufacturers can monitor all of their product as it passes on the assembly line; they can therefore detect the onset of faulty batches and alter their processes appropriately. This increased efficiency reduces the amount of waste that must be discarded and the amount of duplicate processing due to replacement of orders. In some cases, it also decreases or eliminates the time that workers are exposed to toxic chemicals since they can monitor processes via computer.

### ***Technical Description***

Brimrose Corporation of America (Baltimore, MD) has developed a line of AOTFs that they are marketing for NIR spectroscopy applications. An AOTF is an optical device that

uses ultrasonic waves to alter the index of refraction of an optical crystalline medium. It can obtain data in the near infrared with a high degree of wavelength resolution in near-real time.

The AOTF has several advantages over mechanical spectroscopic systems based on rotating devices or moving mirrors. The biggest advantage is speed. It can scan the NIR spectrum more than 30 times per second, as compared to the rate of older technology's ability to scan a range of interest only once per second. Also, because Brimrose's AOTF is solid state, it is rugged and has a lifetime of more than five years at normal duty cycles without damage to the crystal. In addition, the system is pre-aligned and does not require periodic alignment at normal duty cycles.

AOTF spectrometers are based on a device in which a piezoelectric transducer is bonded to a birefringent crystal. The transducer is excited by a radio-frequency (RF) source, which propagates an acoustic wave in the crystal. This acoustic wave modifies the crystal's index of refraction such that incident light is diffracted within the crystal. For a given RF input frequency to the transducer, only a narrow wavelength band of light will exit the crystal at a predetermined angle. By varying the RF source, the wavelength reaching the sample varies, creating the scanning required for complete spectrum. Varying RF frequencies is done very quickly since the device has no mechanical mass to be mobilized.

### ***Environmental Benefits***

NIR spectroscopy offers several advantages that contribute not only to the environment but, at the same time, to the bottom line of the user. For example, NIR spectroscopy systems provide online information about a material's composition so that technicians can control and minimize the amount of solvents and reagents they needed. Therefore, using less of the often toxic and volatile solvents allows these manufacturers to release less pollution.



■ ***Brimrose's online monitor, pictured above, increases manufacturing efficiencies, translating to fewer faulty batches and a smaller amount of toxic chemicals.***

Photo courtesy of Cherie Doyle.



As another payoff, manufacturers using this technology can minimize the total amount of raw material for production. They can realize these savings because NIR spectroscopy optimizes how much material is required for a process in general, minimizing waste. The technology, therefore, lowers the total cost for raw materials needed in a process and conserves valuable, and often nonrenewable, national resources.

Online spectroscopy also prevents manufacturers from producing rejected batches, which represent not only a loss of time and money, but also significant environmental issues. In some processes, rejected batches must be disposed of as hazardous waste—an expense and environmental issue in itself.

Although most companies that have implemented this type of online analysis will not disclose figures related to the money, materials, and time they are saving, Brimrose believes that these savings are substantial. For example, one small polypropylene manufacturer estimates that, even with recycling, noncomplying materials consume several tons of solvents each year and waste significant amounts of energy. With

NIR spectroscopy, such waste can be avoided, translating to associated cost savings.

#### ***Product Status***

Brimrose has sold more than 100 of its NIR spectroscopy systems. Prices for an NIR spectrometer using an AOTF range from about \$50,000 to \$100,000.

#### ***BMDO Origin***

BMDO funded research in acousto-optics for use in optical communications, optical computers, and guidance and surveillance systems.

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## BMDO R&D Controls Mollusks Without Polluting Lakes

### *Environmental Applications*

Zebra mussels have presented a major challenge for electric utilities and manufacturers in the United States. They infest many of the Nation's rivers and lakes and attach themselves to almost any hard surface underwater. Highly prolific in nature, they often form extensive colonies inside com-



■ *The zebra mussel, pictured above, is wreaking havoc on our Nation's waterways by clogging intake pipes at power and manufacturing plants. ODU is demonstrating a way to control these mollusks using pulsed power.*

ponents such as power plant condensers and heat exchanger tubes leading to decreased heat exchange efficiency. They also can inhabit and clog service lines that deliver water for cooling transformers and other critical components.

The zebra mussel has long been a problem in Europe, but is a newcomer to the United States, first found in 1988 in the Great Lakes region. It landed in this region because foreign ships carried the mussel larvae in ballast water. The hardy species has since pervaded many of the Nation's waterways, sighted as far south as Baton Rouge and as far east as the Hudson river. Such rapid spread has sparked considerable concern on the part of utilities and other industries nationwide.

Larvae of zebra mussels are very small, often rendering filtration ineffective. Once the larvae have penetrated an area, they proliferate, forming large colonies. Therefore, many electric utilities and manufacturers with plants positioned along waterways in infested regions have resorted to expensive control systems that, for example, treat the zebra mussels and their larvae with chlorine to eliminate them. In such cases, the treated water must then be dechlorinated to prevent damage to the river's ecosystem.

Utilities have pursued other approaches as well, which, in some instances, have presented labor, time, and safety issues. For example, in a case study involving mature zebra mussel populations, workers at an electric utility in the Great Lakes

region dewatered an infested power plant structure and removed the zebra mussels with a high-powered spray. Because of the extensive amount of flying debris, the workers wore protective body wear. In addition, due to delays in debris removal, a foul odor quickly developed from the decay of the biomatter. Odor raises concern because it can cause oxygen deprivation and expose workers to high levels of decomposition gases such as hydrogen sulfide<sup>8</sup>.

Researchers at Old Dominion University (ODU; Norfolk, VA) are using a BMDO-funded "pseudospark" switch developed at the University of Southern California to eliminate the growth of zebra mussels in water-based systems around power plants and other industrial facilities. Their technology acts as an electric fence, continuously applying ultrashort pulses of electricity. The pulses stun the mussels, continuously preventing them from clinging to the surface and colonizing on pipes and other components.

### *Technical Description*

The pseudospark switch can produce ultrashort electrical pulses of 1 million watts or more. It is made of silicon-doped gallium arsenide, which is counter-doped with copper atoms to produce a semi-insulating material. The switch is activated by a neodymium YAG laser, which energizes electrons that the copper impurities trap. The electrons remain in this energy state for several microseconds and, as long as they are trapped, current flows through the switch. A second laser turns off the current. Optical control of the switch allows researchers to vary the pulse duration with extremely high accuracy.

The short pulses allow for increased power efficiencies and avoid damage to treated components. The pulse duration can be as short as 100 picoseconds, making it the fastest known high-power gated switch. With switching speeds this

Photo courtesy of Lisa Hylton.



fast, the system can deliver short bursts of intense power without significant heat.

#### ***Environmental Benefit***

ODU's pulsed power technology could lead to an efficient, less labor intensive way to control zebra mussels and other biofouling organisms without the use of polluting chemicals such as chlorine. It, therefore, could have considerable payoffs to industry and the industry's surrounding ecosystem. For example, using the system, industries will not have to retreat chlorinated or otherwise chemically treated water before it is released into the ecosystem. Therefore, it may save industries money and labor associated with this task. In addition, the short pulses do not have a thermal effect and, therefore, do not cause thermal pollution.

#### ***Product Status***

ODU is continuing to improve the system through projects supported by the Federal government and industry. Freshwater experiments on the prevention of zebra mussel fouling are currently under way, supported by the U.S. Army and several utility companies.

Field studies where tidal water was used to demonstrate the pulsed electric field effect were very successful. The sys-

tem could completely suppress biofouling when the water was electrically treated. The treatment system's efficiency exceeded 5,000 liters per kilowatt-hour (kWh) for tidal water. For fresh water, this efficiency can easily reach values of 100,000 liters per kWh. In a related project, ODU has been participating in a consortium to develop this technology for eliminating zebra mussels from the ballast water of ships as part of a \$2 million project for the Defense Advanced Research Projects Agency. The consortium includes ODU, the South Tidewater Association of Ship Repairers, the Commonwealth of Virginia, and the City of Norfolk.

#### ***BMDO Origin***

BMDO funded the pulsed power research at both ODU and USC for possible directed energy weapons. The work at ODU was administered by the Office of Naval Research.

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## BMDO R&D May Help Meet Clean Air Standards

### ***Environmental Applications***

Air pollution, whether emitted by stationary sources such as power plants or by mobile sources such as automobiles, has become a serious problem in the United States. Therefore, through incentives and legislation, Federal, state, and local

governments have begun to address this problem; however, new technology will be needed to meet new requirements.

For example, as part of the Clean Air Act Amendment of 1990, legislation requires fossil fuel power plants nationwide to eventually reduce annual sulfur dioxide (SO<sub>2</sub>) emissions by a total of 10 million tons and

nitrogen oxide (NO<sub>x</sub>) emissions by 2 million tons, as compared to 1980 levels. These reductions are occurring in two phases; one phase began in 1995 and another will begin in the year 2000. While certain allowance programs are being implemented to help power plants meet these standards, they will disappear by 2010.

Coal burning power plants reduce emissions in several ways. Some facilities burn low-sulfur coal, which is more prevalent in the western United States but also more expensive. Others use control technologies that capture and/or neutralize hazardous substances before these pollutants enter the environment. While environmental control systems vary, fossil fuel power plants often use flue gas desulfurization systems, more commonly known as scrubbers, to control the emissions of SO<sub>2</sub>. In general, such systems allow combustion gases to pass through tanks containing a material that captures and neutralizes the SO<sub>2</sub>. In 1994, the average scrubber system in the United States was roughly 80 percent efficient, but system efficiency varied drastically, ranging from just under 12 percent to 98 percent.<sup>9</sup> Scrubbers eventually pro-

duce pollution in the form of solid waste, which requires disposal. According to the Electric Power Research Institute, the U.S. electric utility industry spends over \$1 billion each year to dispose of fly ash and scrubber sludge.<sup>10</sup>

Mobile sources, i.e. motor vehicles, are also a target for air quality improvements. While automobiles currently use catalytic converters to reduce emissions, this technology has not been the end-all cure for pollution problems. Vehicles still emit several pollutants that are contributing to serious air quality problems, especially in large metropolitan areas.

### ***Technical Description***

Integrated Applied Physics, Inc. (IAP; Torrance, CA), has demonstrated a high-powered, extremely short-pulse power modulator that may, in the future, be retrofitted onto power plants and mobile pollution sources such as automobiles. In power plants, the modulator can be placed in electrostatic precipitators to decompose pollutants such as SO<sub>2</sub>, NO<sub>x</sub>, and volatile organic compounds. Power plants sometimes use electrostatic precipitators to remove particulates, but the technology currently does not remove gases. IAP's technology can increase the performance of pollution control systems to more than 99 percent while also eliminating scrubber sludge and significantly reducing fly ash.

This technology is based on the use of pulsed corona discharge (PCD). In PCD, a high-voltage, extremely short electrical pulse is applied to form a discharge in a suitable electrode structure. During the formation of the discharge, a nonthermal plasma is produced. The plasma's high-energy electrons cause chemical reactions that either decompose the pollutants into nonhazardous products or convert them to particulates, which the adjoining electrostatic precipitators can remove.

IAP's pulsed modulator solves efficiency problems



■ ***Fossil fuel power plants could use IAP's pulsed power modulator to decompose pollutants such as SO<sub>2</sub>, NO<sub>x</sub>, and volatile organic compounds, with efficiencies approaching 99 percent, while also eliminating scrubber sludge and reducing fly ash.***

Photo courtesy of John Kennedy.



encountered with PCD by properly tailoring the pulses to improve the energy efficiency of the process. PCD was previously demonstrated at an electric utility in Italy where it successfully decomposed pollutants to minute levels. However, the modulator used did not have short pulse capabilities, therefore, the energy efficiency and reliability of the control system suffered. In these earlier systems, the discharge energy was wasted in heating the plasma ions, which do not participate in useful reactions. Short (less than 100-nanosecond) pulse lengths and high energies (100 kilovolts [kV]) are required to increase the efficiency of this process. Also, short pulse rise times of less than 10 nanoseconds and the ability to deliver currents of between 1 and 20 kiloamperes [kA] are required. One experiment demonstrated that a device with such capabilities would increase energy efficiency by a factor of three.

Based on this concept, smaller versions of the modulator can be used on diesel-fueled vehicles to produce 100 to 1,000 very short high-voltage pulses per second, reducing

NO<sub>x</sub> and other pollutants. A smaller-scale device similar in operation to the smoke stack control technology could be incorporated into the tailpipes of diesel vehicles, trucks, ships, or other equipment to virtually eliminate NO<sub>x</sub> and other emissions.

To this end, the U.S. Navy is funding a project at the University of Southern California (USC; Los Angeles, CA) for compliance with diesel engine emission requirements. USC researchers are working with a researcher from the Urals branch of Russia's Institute of Electrophysics, improving the process efficiency and successfully demonstrating several applications, including its use in the exhaust system of a diesel Volkswagen Golf automobile and a large diesel engine. The device was also tested on stationary diesel engines at Port Hueneme (Ventura County, CA) for future use on Navy ships. Current work on this application focuses on converting nitric oxide (NO) emissions into nitrogen dioxide (NO<sub>2</sub>). This work taps into research originally funded by BMDO.



### ***Environmental Benefit***

Emissions control technologies prevent higher pollution levels, which can cause health problems such as cancer and environmental problems such as acid rain. For power plant applications, IAP's technology can reduce the amount of nitrogen oxides and sulfur dioxides in smoke stack emissions, helping electric utilities comply with new regulations and reduce the amount of pollution that they emit into nearby communities. It also minimizes the amount of scrubber sludge, reducing corresponding disposal needs and associated costs. The technology, when used on mobile sources, is an improvement over catalytic converters and would be of special benefit to large metropolitan areas with high concentrations of automobiles and elevated pollution levels from automobile exhaust.

### ***Product Status***

As a first step, the company is selling modular products such as the BNE-50-2-4 short pulse, high voltage power supply, which can deliver 50 kV pulses at 2kA with a pulse width of 200 nanoseconds. For power plants, IAP has developed an experimental prototype; engineers could assemble several prototypes in a series to demonstrate power-plant-level applications.

### ***BMDO Origin***

The first development contributing to this modulator, the back-lighted thyatron (BLT), was funded by BMDO at the USC in the late 1980s. The BLT is a high-power gaseous-discharge switch used in pulse power electric generators. By using an optical signal to trigger the switch instead of an electrical signal, the BLT can provide fast current rise (over 6 x 10<sup>11</sup> amperes per second), high peak current, and high

power gain (in the range of 1,000 to 10,000) in a small, lightweight package. BMDO funded BLT research at USC to charge directed energy weapons. Because the BLT is smaller than standard thyatrons, conducts higher current, and does not require standby power, it is especially attractive for long-term use in space. IAP has since received BMDO SBIR contracts for modulator development for similar reasons.

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Photo courtesy of Lisa Hylton.



## Packing a Powerful Punch for Purifying Water

### ***Environmental Applications***

While the world's population is growing, its resources for drinking water are diminishing, placing considerable stress on urban planners as they seek new supplies that will not adversely affect ecosystems or quickly dry up. This problem is underscored when understanding that, while 80 percent of the Earth's surface is water, 97 percent of that water is saltwater in oceans and seas, and another 2 percent is tied up in the polar ice caps.<sup>11</sup> Therefore, many municipalities throughout the world, especially in arid areas such as the Middle East, have been relying on technology to supply its populations with desalinated water for drinking and irrigation. In taking this approach, these municipalities face some key issues.

One issue revolves around energy efficiency. Current desalinization technologies, such as thermal evaporation, electrodialysis, and reverse osmosis, consume significant amounts of energy, leading to higher costs and added pollution associated with energy production and consumption. Another issue revolves around maintenance, since these systems typically are mechanical and have moving parts that either must be regularly replaced (such as filters) or maintained. A third issue is the desire to tap into underground brackish water sources (saltwater with salt content less than 3,000 parts per million), because these sources comprise a large portion of the world's water supply. Tapping into such sources allows municipalities to site their plants far inland, avoiding the need to shut down operations during oil spills or red tides.

Researchers at the Lawrence Livermore National Laboratory (LLNL; Livermore, CA), have developed a technology called capacitive deionization (CDI), which can address these concerns. This technology, now marketed by the

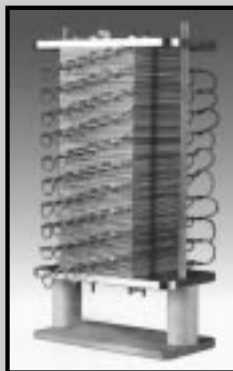
FarWest Group, Inc. (FWG; Tucson, AZ), is a brick-shaped system that uses carbon aerogel to separate inorganic material from water. CDI is projected to use 10 to 20 times less energy per gallon of purified water than conventional purification methods. It also has cost and maintenance advantages over existing technology. Its first market is in the treatment of underground brackish water; and to this end, Alameda County, CA is testing samples, hoping to use it as a water management tool for ornamental and lawn irrigation applications.

CDI can also remove heavy metals and hazardous materials from wastewater streams. It can also treat heat exchanger and boiler feed water in fossil-fuel and nuclear power plants and reclaim salt and other minerals from wastewater streams on a large scale. The U.S. Navy, U.S. Army, University of Arizona, and Rutgers University are investigating some of these applications.

### ***Technical Description***

In the CDI process, water containing salt, heavy metals, or even radioactive isotopes is pumped through a stack of carbon-aerogel electrodes. The electrodes are pancake-thin titanium plates onto which paper-thin aerogel is glued on both sides and have a very high specific surface area of 400 to 1,000 square meters per gram. An electric potential is then applied across the electrodes, which attract the negatively and positively charged ions. The effluent from the stack is purified water.

When the aerogel is saturated with contaminants, the electrodes are shorted and the trapped ions are released through a stream of rinse water (at a reduced flow rate to yield a small volume of water with a high concentration of the dissolved solids). CDI can produce a continuous flow of purified water by operating two stacks of carbon aerogel electrodes in parallel; one stack purifies, while the other is elec-



■ Pictured above is a stack of 192 carbon-aerogel electrodes. The stack, which stands about 2 feet high, can treat brackish water at the rate of about half a gallon a minute.

Photo courtesy of Renan Kiper.



trically regenerated. User-friendly computerized controls allow automated operation.

#### ***Environmental Benefit***

According to the LLNL studies, this method is more energy efficient than competing technologies by as much as one order of magnitude. The capacitive deionization system has no moving parts, so there are no mechanical breakdowns. Also, electrostatic regeneration does not use acids, bases, or salt solutions like ion-exchange systems, so those associated expenses and waste disposal concerns are eliminated.

#### ***Product Status***

FWG, a water resources management business, recognized the world-wide potential of CDI for water treatment services. In 1997, the company established a licensing agreement with the LLNL to commercialize CDI technology. A second license was established to ensure that FWG could manufacture enough carbon aerogel to support its commercial plan.

FWG has implemented a multi-faceted commercialization approach. In addition to demonstrating CDI's capabilities

in both the United States and abroad, the company is consulting with Boeing Aerospace and Interglobal, Inc., for international distribution. FWG recently obtained \$375,000 from an electric utility company to finance the installation of a proof of performance system in Carlsbad, California. Additional funding is being sought to speed development of this technology.

#### ***BMDO Origin***

In the early 1990s, LLNL's research on carbon aerogel was partially funded by BMDO's space power program to develop lighter batteries.

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## BMDO R&D Gives Food and Drink a Clean Bill of Health

### **Environmental Applications**

All countries, both developed and less developed, need better technologies for protecting their food and water against health-threatening micro-organisms. There is no fool-proof way currently being used by municipalities that will protect populations from all of the various contaminants. For example, *Cryptosporidium* is a concern in developing countries as well as in the United States, where, for example, it sickened about 400 people in the Milwaukee area during the summer of 1993.<sup>12</sup> Unfortunately, water treatment plants do not remove or kill this micro-organism.

PurePulse Technologies, Inc. (San Diego, CA), a subsidiary of Maxwell Technologies (same location), is commercializing two pulsed power-based purification systems that address the limitations of conventional techniques for microbial decontamination. These systems are called PureBright® and CoolPure®.



■ **PureBright, pictured above, offers a strong line of defense against micro-organisms, including water-borne *Cryptosporidium*. It is being used by a major fast food chain for decontaminating water.**

### **Technical Description**

The PureBright system is effective against highly resistant micro-organisms, including *Cryptosporidium*—which many conventional systems fail to control—and meets stringent treatment standards for pharmaceutical product sterilization. Utilizing high-energy density capacitors, it uses concentrated energy in short, high-intensity light pulses to kill micro-organisms without using heat, chemicals, or ionizing radiation. High peak power pulses of electrical energy from the capacitors are used to produce intense pulses of light that provide unique bactericidal effects. A key environmental benefit is that it does not pollute the environment because it does not use ionizing radiation or harmful chemicals.

This product kills micro-organisms such as vegetative bacteria, yeasts, molds, bacterial spores, and viruses. Its kill rate is 100 to 10,000 times that of traditional UV light treatments

such as high-power mercury lamps. The light does not penetrate opaque materials, but is transmitted through many types of clear packaging materials, fluids, and air. PureBright's extremely short exposure time greatly reduces the potential for material degradation. The treatment is a clean process, leaving no chemical residues and requiring no evacuation steps.

The other product, CoolPure, decontaminates opaque or cloudy liquids and liquid foods. It is effective for preserving food without using ionizing radiation or synthetic chemicals. It uses pulses of high-intensity electric fields, produced with the same type of capacitors as PureBright, to kill spoilage organisms and pathogens in pumpable liquid products.

CoolPure avoids the high temperatures and accompanying thermal damage that occur with heat pasteurization. The process kills high levels of vegetative micro-organisms through massive electroporation, or rupturing, of microbial cell membranes. CoolPure may also enhance the yield of some pharmaceutical and biotechnical processes.

Fruit juices are one of its biggest prospective applications because it can extend the shelf-life of fresh orange juice, for example, while retaining flavor and Vitamin C content. It has no effect on the taste, chemistry, or functionality of the food or liquid.

### **Environmental Benefit**

PureBright technology would prevent sickness and death from micro-organisms and improve the quality of life. It would also help the economy by allowing restaurants to set up businesses in areas that were previously unrealistic due to poor water quality.

CoolPure will allow the fresh juice industry to sell a longer-lasting product. There will be more time to transport juice over longer distances and consumers will throw away spoiled juice less frequently.

Photo courtesy of Leslie Aitchison.



### **Product Status**

PurePulse Technologies is commercializing both systems. In July 1995, the U.S. Food and Drug Administration (FDA) cleared the use of CoolPure for the low-temperature preservation of liquid foods. In September 1996, FDA cleared PureBright technology for killing bacteria on food. The company has deals with Tetra Pak and Automatic Liquid Packaging to commercialize the PureBright process for food and pharmaceutical packaging, respectively. In another example, PurePulse and a major manufacturer in the health care field are pursuing a licensing and purchase agreement to use PureBright technology for sterilizing disposable consumer products.

In addition, PureBright is now being developed for water treatment for restaurant use. It has received a \$1 million grant from a large international food chain and has developed a system that can clean four gallons of water per minute. The device easily fits into commercial kitchens. The system will allow restaurants to serve their customers safer and better-tasting water, hot and cold beverages, and ice cubes. With field testing nearly complete, the water purifier will soon enter the marketplace.

PurePulse is also making significant inroads in the indus-

trial field. In early 1998, the company signed an agreement with Pall Corporation, which could lead to the commercialization of its PureBright technology for producing high-purity water for the semiconductor industry.

While CoolPure technology is still being refined for high-capacity commercial applications, PurePulse plans to market a low-capacity system for laboratory and research communities. The system, which offers a flow-through rate of 10 liters per hour is now available.

### **BMDO Origin**

BMDO partially funded the development of high-energy density capacitors to produce a compact, lightweight device that could provide pulsed power for space-based lasers and accelerators. This capacitor is key to producing the pulsed light and electric fields for both PureBright and CoolPure systems.

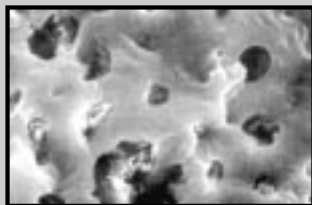
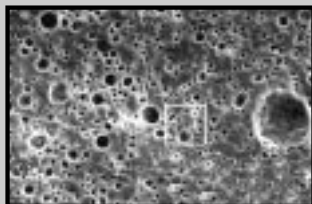
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## Materials Process Poses as Cleaner Choice

### ***Environmental Applications***

Some industries and government facilities dispose of hazardous material by incinerating it because incineration occurs at temperatures theoretically high enough to breakdown the complex, toxic compounds into simpler, inoffensive components. However, environmental groups object to this method, arguing that the temperatures are not high enough and that the exhaust systems are not monitored frequently enough to ensure the complete breakdown of all toxic compounds. Additionally, in recent years, many communities have taken the "not in my backyard" position, making it difficult to locate new sites and build new facilities. Hazardous waste incinerators are especially prone to this type of public outcry because their emissions, although below maximum allowable levels, still release



■ ***HfMI's neutralization and encapsulation method can improve the safety and lower the cost for disposal of toxic compounds such as trichloroethylene. This project revolves around the development of highly filled material, pictured above.***

traces of especially offensive pollutants such as lead, mercury, and beryllium.

The Stevens Institute of Technology's Highly Filled Materials Institute (HfMI; Hoboken, NJ) developed a neutralization and encapsulation method that could replace incineration. This disposal technique can improve the safety and lower the cost of disposal operations. It can be used to treat any substance that has a known neutralizing agent. For example, it can detoxify trichloroethylene, a chemical commonly used for metal degreasing, solvent extraction, and dry cleaning.

### ***Technical Description***

HfMI, in support of BMDO and other organizations, has been developing advanced material systems, called highly filled materials, in which polymer binders or low molecular

weight liquids are mixed with large amounts of particulate or powder materials. The Institute's approach is to continuously process the highly filled materials using twin screw extruders, introducing polymeric binders and powders at various phases of the extrusion process. The degree of mixedness throughout all phases and the particle size distribution of the solid phase during processing are important elements of the process development. To meet stringent requirements, HfMI optimizes the design of the extruders, which have screws of varying configurations and sizes, so that mixing will be accomplished correctly throughout all phases depending on the type of material that the fabricators are producing. After the material is mixed, it is forced into a die to be formed into its net shape using the extruder.

For environmental applications, the process used to make highly filled materials can be modified to chemically neutralize and trap toxic substances. In this scenario, the hazardous material is fed into a twin screw extruder, where it is introduced to a neutralizing agent and placed into a polymeric matrix. The dispersion of neutralization products as droplets in a second polymeric matrix encapsulates the hazardous material to further trap it. After it is encapsulated, the material is extruded in cylindrical strips that contain another polymeric barrier coating. For example, HfMI demonstrated the process using alkaline hydrolysis to neutralize trichloroethylene, a chemical commonly used for metal degreasing, solvent extraction, and dry cleaning. The solution was formed into a gel using an acrylic acid polymer and then encapsulated in an epoxy polymer. This method can be used to treat any substance that has a known neutralizing agent, including chemical munitions.

### ***Environmental Benefit***

HfMI's method costs less than incineration and eliminates the public's exposure to incinerator emissions. In terms of

Photo courtesy of Renan Kiper.



economics, it is especially ideal for smaller remediation sites because it eliminates the need to build incineration facilities. And because the encapsulated material is either nontoxic or less toxic, it is less subject to risk and cost issues revolving around the transport of hazardous waste. It therefore can be easily transported at a much lower cost from the contamination site to a centralized disposal facility. The application of HfMI's technology to dispose of chemical munitions can potentially save billions of dollars by reducing the number of incinerator plants from the 10 currently planned to only 1.

#### ***Product Status***

HfMI has patented its method and, as previously mentioned, demonstrated it on trichloroethylene. The Institute is interested in collaborative efforts to move the technology to commercial markets and mass production.

#### ***BMDO Origin***

Work in highly filled materials at Stevens Institute of Technology began in 1986, initiated by BMDO (then the Strategic Defense Initiative Organization) to process, model,

and characterize highly filled materials. For BMDO, these materials are useful in producing rocket fuels because they have more than 90-percent solid content by weight (60 to 70 percent by volume), allowing the fuels' propulsive force to be packed into the smallest volume possible. As a result, BMDO's Innovative Science and Technology program encouraged the formation of a comprehensive center (HfMI) that has served both defense and industry. BMDO work was managed at the Office of Naval Research. Since then, groups such the U.S. Army, U.S. Navy, and industries have tapped into HfMI's resources.

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## How Will We Handle Nuclear Waste in the Future?

### ***Environmental Applications***

Between 1968 and 1994, the 118 light water nuclear reactors in the United States (some of which have been decommissioned) discharged more than 30,000 metric tons of uranium.<sup>13</sup> Of the 110 reactors expected to be in operation by the year 2000, 9 are projected to reach on-site storage capacity before the turn of the century. Moreover, according to



■ *Investigating a concept called ATW, researchers have been finding ways to use particle beam accelerators, pictured above, to reduce the impact of nuclear waste.*

Los Alamos National Laboratory (LANL; Los Alamos, NM) researchers, 70,000 metric tons of this waste will require disposal by the year 2012. Associated electric utilities will be required to either expand these on-site facilities or find alternative means or sites for storing waste. Additional storage

needs raise many economic, regulatory, transportation, and public relations issues, because nuclear wastes are not only highly toxic but also long lasting, with half-lives extending beyond 10,000 years. Unfortunately, there is no available approach to treat spent fuel to make it less toxic or reduce its half life. With current trends and technology, radioactive spent fuel amounts will increase, remaining in pools and vaults for many, many generations to come.

### ***Technical Description***

Researchers at LANL have been working with a technology called accelerator-driven transmutation of waste (ATW), which is being designed to transform plutonium, higher actinides, and environmentally hazardous fission products into safer elements. ATW does not eliminate the need for permanent waste storage, but instead, enhances its viability by transforming longer-lived elements into more stable elements with shorter half-lives.

Transmutation is the nuclear change of one element into another. In transmutation of nuclear waste, radioactive material is bombarded by high energy protons. This process, known as induced fission, divides the radioactive element's nucleus into two nuclei of comparable weight, resulting in new elements which are either more weakly radioactive, or non-radioactive.

An ATW facility will consist of a high-power proton linear accelerator, a spent-fuel treatment system, a waste clean-up system, and a subcritical burner producing and using an intense neutron field. The subcritical waste burner system is driven by the accelerator's proton beam striking a heavy metal target to produce the required high-power neutron source that drives the transmutation.

The front end of the process is the accelerator, which moves atomic or subatomic particles to high speeds, while magnetic fields control the beam's direction. High-power linear accelerators use carefully controlled electromagnetic fields (supplied by a radio frequency power source) that rapidly alternate to maximize acceleration. The considered accelerator is a smaller version of one being designed for another LANL project called accelerator production of tritium (APT). The design uses demonstrated components to transmit the beam through the different energy regimes leading to the 40 megawatt driver beam for the subcritical burner.

### ***Environmental Benefits***

ATW has the potential to be a world-changing technology, offering benefits not only to a single industry (i.e. electric utilities) but also to the safety and welfare of our Nation as a whole. Although the technology cannot completely eliminate nuclear waste, it can reduce it to much lower quantities that can be stored more easily for shorter periods of time. Most of



Photo courtesy of Linda Voss.



the radioactivity in this remaining waste would decay in less than 300 years, compared to half-lives of millions or billions of years for untreated products.

ATW systems could theoretically be used on utility sites, greatly reducing the amount of waste requiring transport, thereby increasing the safety of public highway and railroad systems. It therefore can help solve some of policy makers' issues concerning the transport of nuclear waste, which will have to be carried thousands of miles, over multiple state lines, across the Nation.

### ***Product Status***

LANL is working with France, Italy, Sweden, Spain, the Czech Republic, Russia, Japan, and South Korea on major ATW programs. The United States and the European Community are jointly helping this technology development through the International Science and Technology Center. Russian researchers are building a high-power liquid lead and bismuth spallation target. This target is the last major component required for a demonstration of ATW. The target is scheduled for testing in the year 2000. Industry has shown interest as well, and LANL is in discussions with

Westinghouse, Bechtel, Northrup Grumman, and General Atomics. LANL also works with the U.S. Department of Energy to establish a research and development program for moving the technology forward.

### ***BMDO Origin***

BMDO funded neutral particle beam research at LANL for weapons systems. The accelerators were designed to produce energetic beams of either ionized or neutral atoms. Many projects were funded by BMDO such as the accelerator test stand, beam-direction sensing, drift tube linear accelerator, and ground test accelerator, which contributed to ATW.

The general technology used in the RFQ accelerator was developed, in part, with SDIO/BMDO funding. The actual machines proposed for ATW are an outgrowth of the DOE-funded accelerator for tritium production.

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## Endnotes

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